Performance Enhancements to NIF Contribute to Progress Toward Inertial Fusion Energy

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IFE Science & Technology Community
Strategic Planning Workshop
February 2022

LLNL-MI-831877

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

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NIF has been operating for a decade, leading to the threshold of ignition

192 beams
- 1.9 MJ / 500 TW
- 351 nm

4 CPA beamlets
- 4 x 1 kJ ~ 38 ps
- 4 x 250 J ~ 1 ps
- 1053 nm

NIF performance enhancements can benefit both ICF and IFE

- The NIF laser provides a unique combination of high accuracy & precision and high energy & power delivered to the target
- Recent experiments on the threshold of ignition – including N210808 (1.35MJ yield) and its repeats – have shown that we are on a steep performance curve
- **Modest improvements can have a big impact**

See [1]

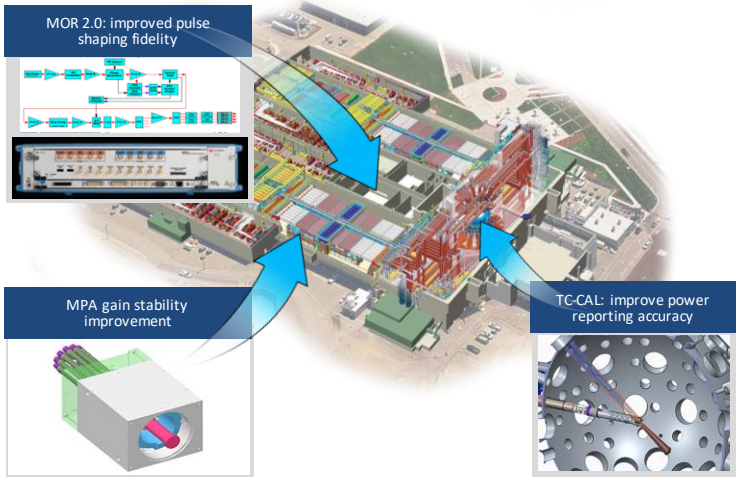
1. Increased accuracy and precision – shot-to-shot reproducibility – allow better control of low-mode implosion symmetry and a faster learning rate
2. Increased laser energy and power provides enhanced capsule performance margin and higher yields

- **NIF has more headroom for both performance enhancements**
- Moving up the performance curve supports both ICF and IFE

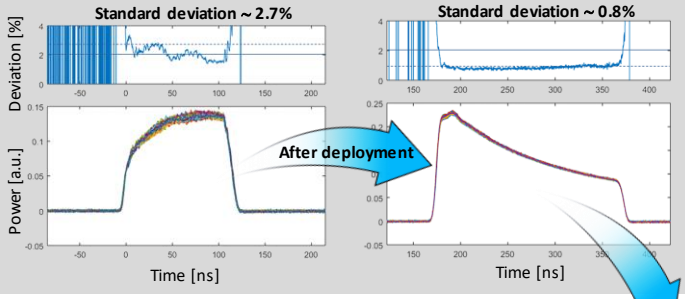
[1] O. Hurricane, O. Hurricane, D. Callahan, A. Kritcher and A. Zylstra White Paper for this IFE workshop (2022)

NIF's energy and precision have gradually improved since commissioning

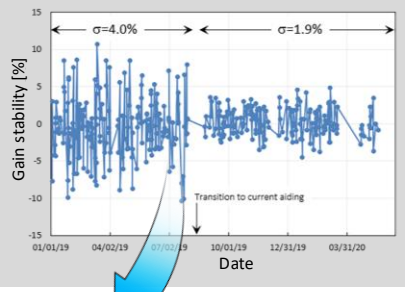
- The NIF laser is operating at its highest sustained levels of energy and power to date, made possible by continued investments by NNSA in optics and laser technology
  - Recent ignition implosions driven at 1.92 MJ, 440 TW
- The fidelity of the laser models, accuracy of the laser diagnostic, beam quality, front-end performance and low-mode symmetry have been all improved
  - Deviation from request <2.5% at the peak and <5% elsewhere



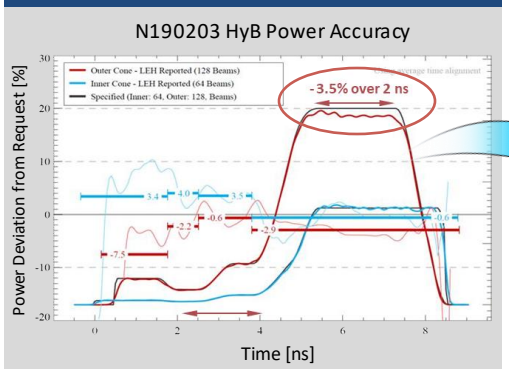
Shot-to-shot pre-shaped pulse stability improved x3 [1]



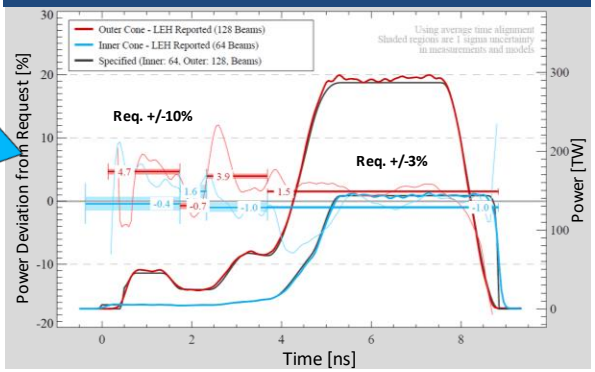
Pre-amp. Gain stability improved x2



Mitigated 3ω "droop" & conversion eff. loss



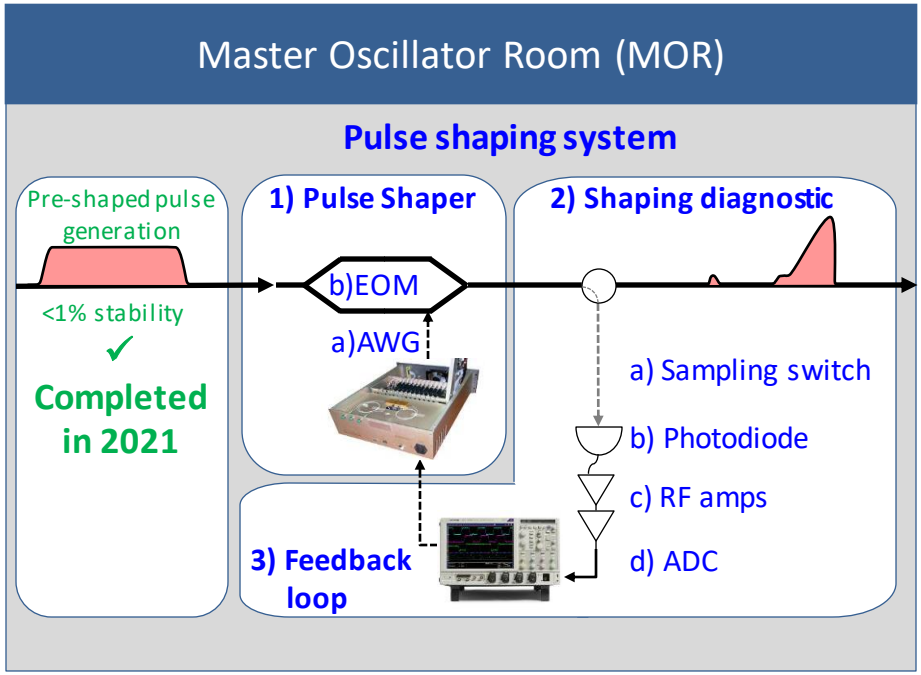
N210808 HyE Power Accuracy met all requirements

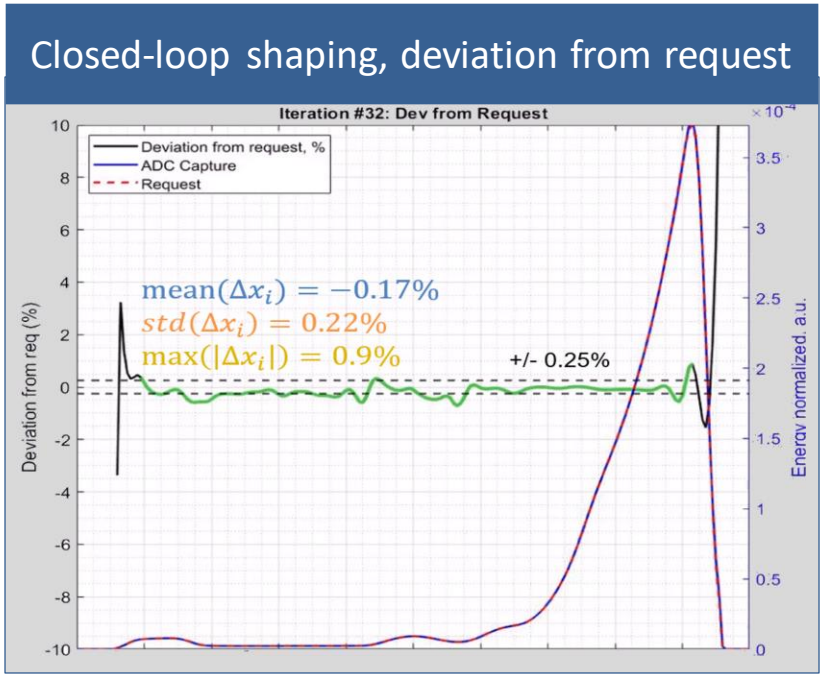


The NIF laser has capability for higher precision/accuracy and power/energy performance

[1] J. M. Di Nicola *et al.*, High Power Lasers for Fusion Research VI **11666** (2021)

Improved stability of the pulse shaping system in the MOR will enhance the shot-to-shot reproducibility of high-contrast pulses on target [1]

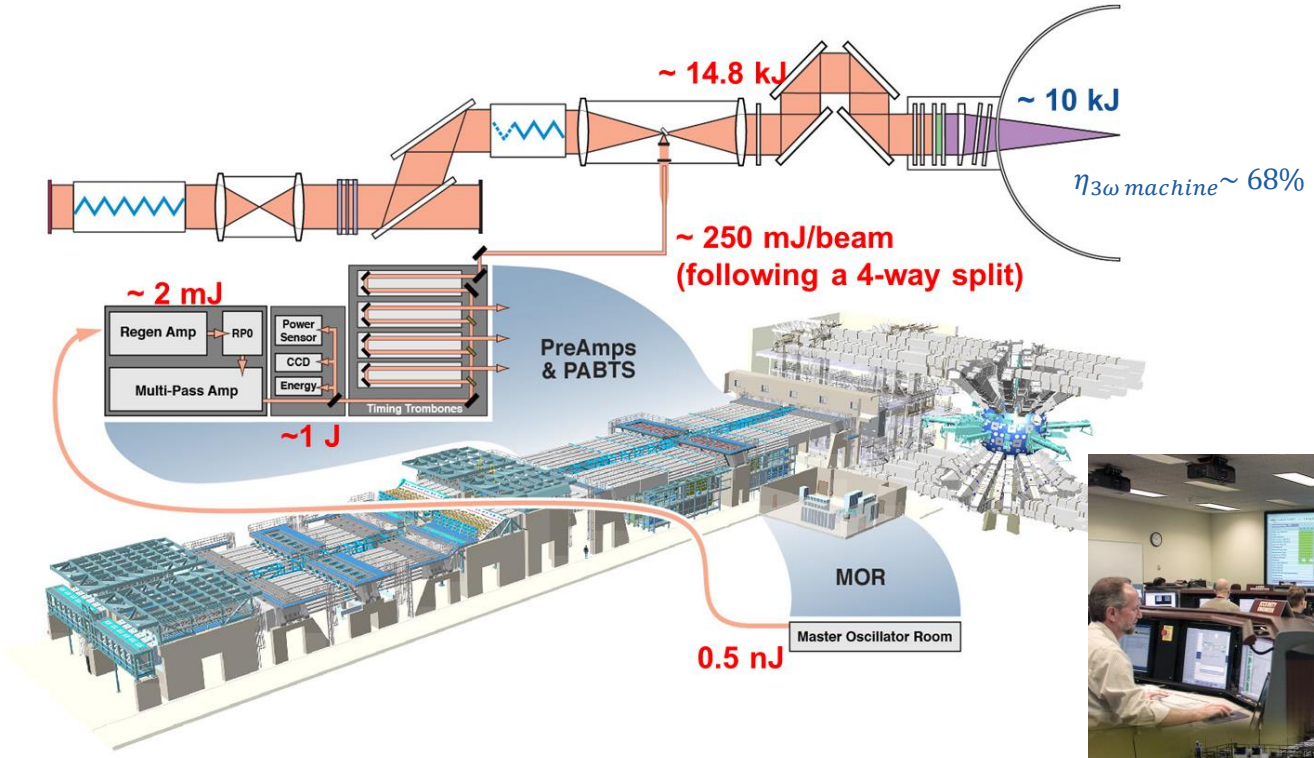




- For key features, 3-5x improvements compared to the deployed system are expected
- Prototype results have shown expected improvements
  - Short-term pulse shape stability at 200:1 contrast <2% (4x improvement demonstrated)
  - Closed-loop pulse shaping and deviation from request <0.5%
- Test of upgraded hardware started on NIF, with deployment completion expected this year

[1] J. M. Di Nicola *et al.*, High Power Lasers for Fusion Research VI **11666** (2021)

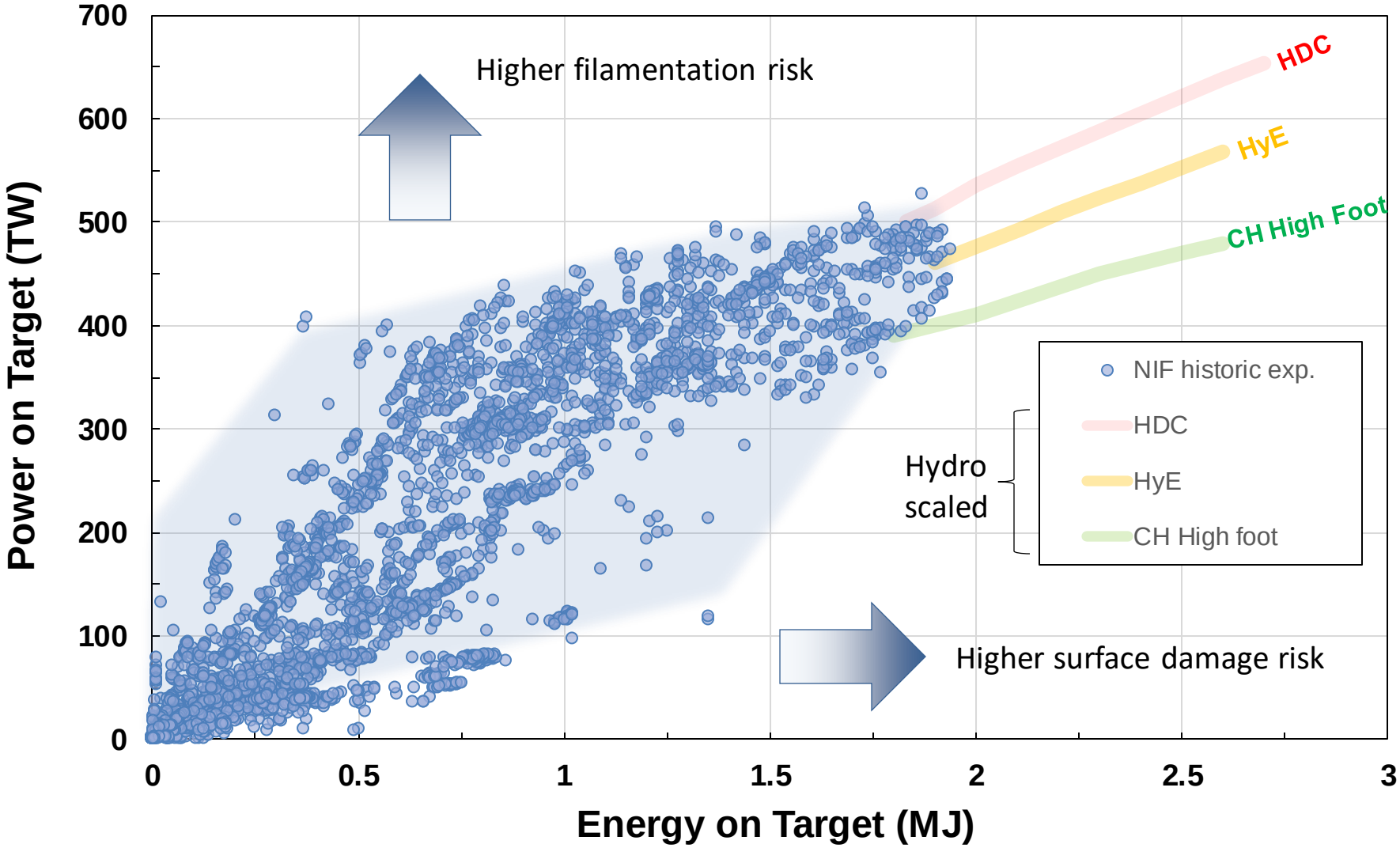
For HyE experiments like N210808, the IR energy was ~2.8 MJ, only a fraction of the 4.2 MJ already demonstrated during NIF commissioning



"Description of the NIF Laser" M. Spaeth et al., Fusion Sc. and Tech. **69** (2016)

The NIF laser engine has capability for higher power/energy performance

NIF has supported ~5000 experiments, including ignition experiments with various pulse shape families & corresponding hydro-scaled trajectories

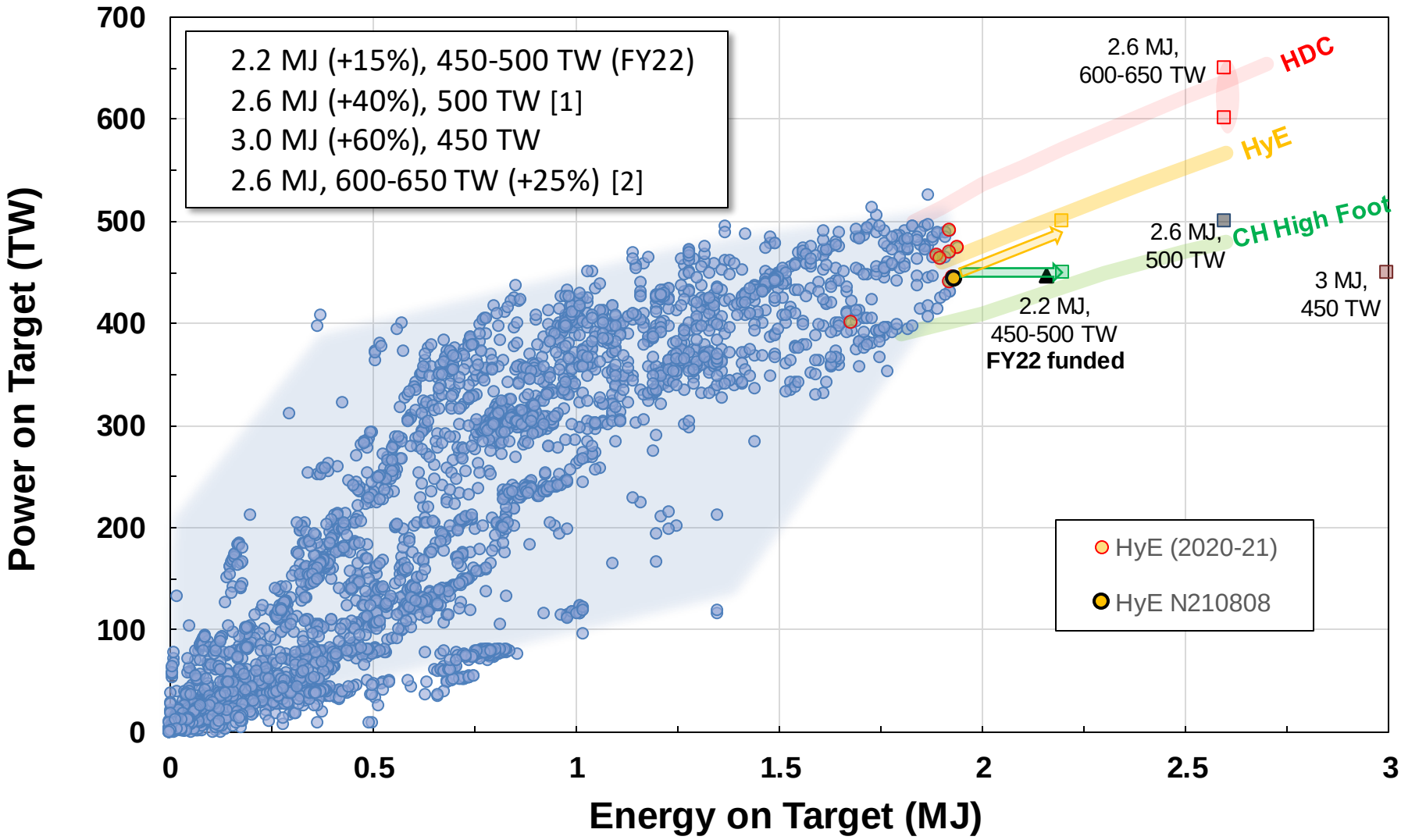


NIF has headroom to get as high as 2.6 MJ, 600-650TW or 3MJ, 450TW

- **Laser experiments sampling the P&E space, projections from integrated simulations and progress in optics S&T have proven that NIF has not yet reached its full-potential**
  - Laser performance campaigns explored the power & energy space.
    - Proof-of-principle for higher power and energy
    - Uncovered issues like filamentation, leading to mitigation strategies
  - Optics S&T developments:
    - Allow for better debris control & reduction of damage initiation
    - Hardening of the optics against laser damage
- In CY22, planned improvements will enable 2.2 MJ (+15% from current), 450-500 TW HyE pulse shapes

Further improvements require completion of NIF Sustainment efforts planned to begin in FY23

The path of further improvements is driven by Users needs and requires further funding and some R&D



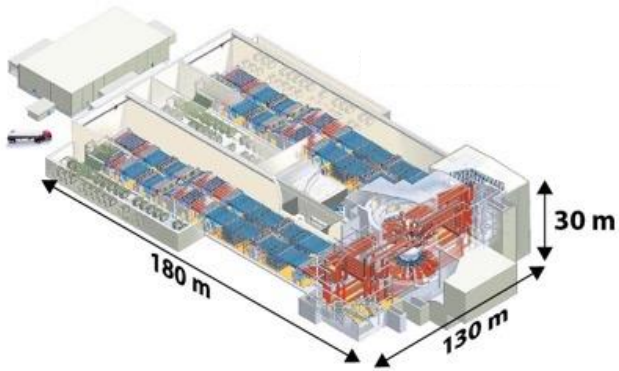
[1] J. M. Di Nicola et al., Nuclear Fusion **59**, 12, 032004 (2019)

[2] Unpublished 2020-2021 integrated laser campaigns and simulation results

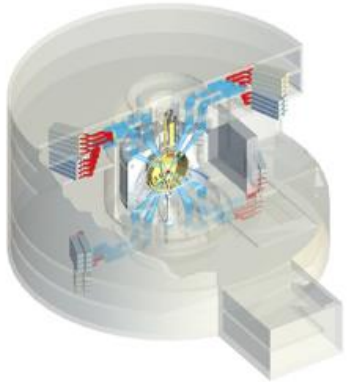
NAS 2013*: “Planning should begin for making effective use of the NIF as one of the major program elements in an assessment of the feasibility of IFE”

- The NIF is a scientific exploration facility, different from the design of an IFE power plant
- However, NIF provides a unique opportunity for experiments at “ignition scale”

NIF: Single Shot



IFE plant: >10 Hz



**An Assessment of the Prospects for Inertial Fusion Energy, Committee on the Prospects for Inertial Confinement Fusion Energy Systems, NRC (National Academies Press, Washington, D.C., 2013)*

NIF is a NNSA facility for SSP, but it could be leveraged it for IFE studies

NIF can uniquely contribute to answering key questions common to ICF and IFE

Ignition and High Gain

- Hohlraum physics (for indirect-drive)
- Polar Direct-Drive (PDD)
- Shock-ignition
- Fast-ignition
- Alternate concepts
- Laser-plasma interaction physics
- Ablation physics
- Instabilities and mix
- Symmetry control
- Real-world fabrication and alignment tolerances
- Burn physics studies

Materials Damage & survivability

- Pulsed high doses of neutrons
- Damage cascades
- Electrical properties
- Optical properties (fiber optics, coatings)

Materials Properties and EOS

At high temperature, high density, high pressure:

- Phase transition rates
- EOS
- Conditions at which phase boundaries occur
- Response of materials to gradients and rapidly evolving temperature and electromagnetic fields

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